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Triboelectrostatic beneficiation of fly ash

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Abstract

Dry triboelectrostatic separations of fly ash derived from both coal combustion and the combustion of coal mixed with 10 wt% biomass were conducted. Two different types of triboelectrostatic separators — parallel plate and louvered plate separators — were used for this study. It is found that the material of construction for the tribocharger in the louvered plate separator affects both the deposition pattern and the quantity of recovery of the separated products. The poor quality of separation for the biomass fly ash studied is probably due to the physical/chemical nature of the biomass fly ash which is significantly different from that of coal fly ash. Published by Elsevier Science Ltd.

Keywords: Triboelectrostatic; Fly ash; Biomass

1. Introduction

The utilization of power-plant-derived fly ash has an impact on the cost of power production from coal. The usage has been hindered by recent shifts to low NO_x burners which can increase the carbon content of the ash above the specification for its use in Portland cement. Due to the drastic changes in the carbon content in fly ash, post-combustion beneficiation has been a recent focus of research [1–7]. The post-combustion beneficiations can generate valuable unburned organic product and inorganic fly ash products, and these two constituents can be collected and used as commercial products. The unburned organic fraction can be recycled back to the burner as fuel or used as catalyst, activated carbon, or catalysts support [4,7–10]. The purified inorganic fraction can be utilized as cement additives [11]. Improved beneficiation and utilization schemes for fly ash can transform it from a waste material, with associated disposal costs, to a valuable product.

Electrostatic beneficiation of fly ash to separate unburned carbon has been investigated widely as an alternate to the other post-combustion cleaning technologies [1–6]. Triboelectrostatic beneficiation of fly ash is a dry method that does not have the disadvantages of wet cleaning, subsequent drying, and the processing of accompanying aqueous waste. In this process, fly ash is charged by triboelectrification. When two materials are in contact, electrons move until the energy level of electrons in each material at the interface is equalized. The material with a higher affinity for electrons gains electrons and charges negatively, while the material with the lower affinity loses electrons and charges positively. A measure of the relative affinity for electrons is the work function. The values of work function of various compounds in fly ash such as unburned carbon, Cu, Al_2O_3, MgO, and SiO_2 are 4.0, 4.38, 4.7, 4.5 and 5.4, respectively [1].

Fig. 1 shows the principle of a triboelectrostatic separation system for recovering the unburned carbon. Particles of unburned carbon (carbon; 4.0 eV) and minerals (SiO_2; 5.00, Al_2O_3; 4.7 eV) can be imparted positive and negative surface charges, respectively, with the copper (Cu; 4.38 eV) tribocharger due to differences in the work function values of the particles and the tribocharger, and can be separated by passing them through an external electric field. The differential charging of unburned carbon and its mineral impurities, achieved in the triboelectrostatic method, makes it possible to use a static high voltage separator to direct the unburned carbon and mineral refuse into separate receivers as shown in Fig. 1. Organic (unburned carbon) particles are attracted to the negative plate, and minerals are attracted to the positive plate. Unburned carbon samples deposited on the electrodes as well as those passing through the separation chamber can be collected and analyzed to determine separation efficiency.

The co-firing schemes of coal with biomass in coal-fired boilers have generated some interest recently due to the potential benefits of lowering the emissions of anthropogenic carbon dioxide and other greenhouse gases. The potential biomass material being studied in the National

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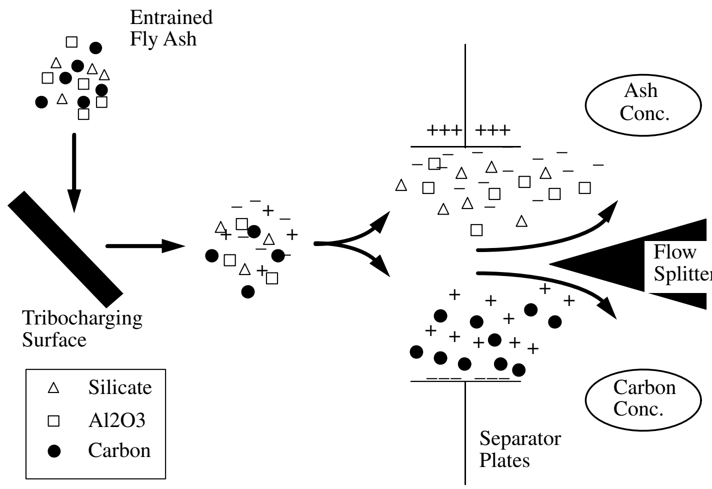

Fig. 1. Principles of triboelectrostatic separation.

Energy Technology Laboratory's (NETL) 500 lb/h combustor included switch grass, hybrid willow and other carbonaceous material. However, the effects on separation of the fly ash derived from the combustion of coal mixed with biomass need further study.

Researchers at NETL have developed dry electrostatic separation technology for the removal of mineral impurities from pulverized coal [12,13] over the last several years. These techniques have recently been applied to the separation of carbon from fly ash to yield an ash rich product that meets specifications for use in concrete application. The ability to efficiently extract high purity carbon or ash from coal fly ash is important in the development and application of cost-effective beneficiation technologies for the production of value-added products. In addition to a typical fly ash sample studied in the past, we also use samples of biomass fly ash to investigate the effects of separation associated with different feed sources.

2. Methods

Triboelectrostatic research at the NETL has focused on development of the totally pneumatic systems without

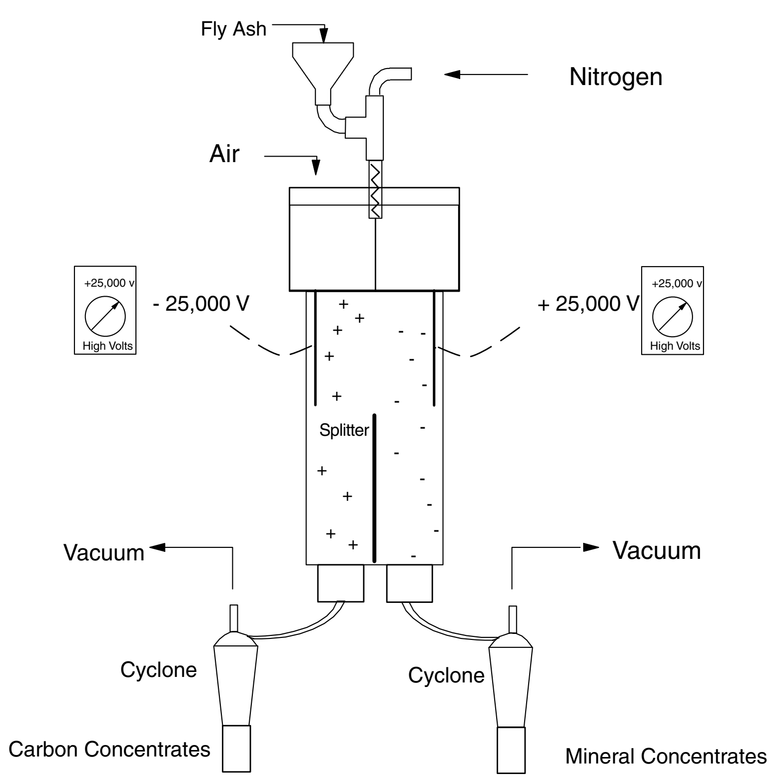

Fig. 2. Schematic diagram of a parallel plate separator.

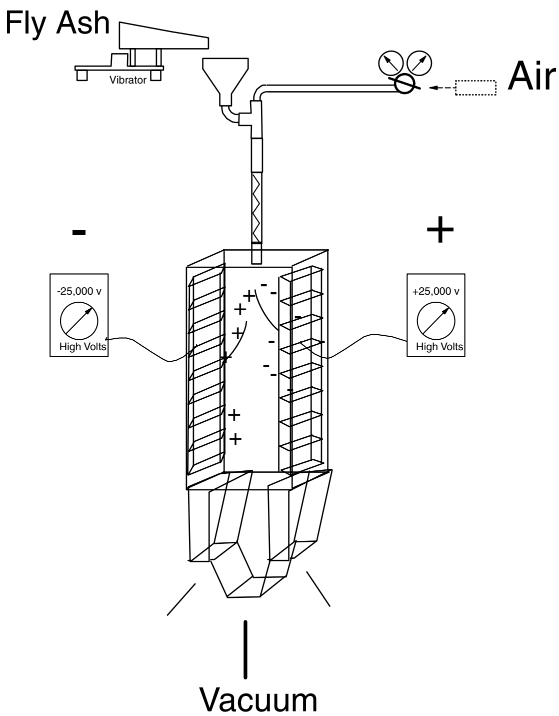

Fig. 3. Schematic diagram of a louvered plate separator.

mechanical charging devices. Two different types of separators — parallel plate [13] and louvered plate — were used for this study. The parallel plate separator consists of a venturi feed system driven by pressurized nitrogen gas, an injection nozzle, and a high voltage separation section (Fig. 2). The fly ash particles pass through the venturi feeder and become charged in this turbulent flow zone by contact with the copper tubing and with one another. The contact of the particles with copper surfaces, especially in the turbulent zone of the in line static mixer, results in effective charging of both unburned carbon and mineral. These charged particles are then forced out the nozzle in a ribbon of entrained particles approximately 7.62×0.3175 cm. This plume of particles is directed between two parallel charged plates 15.24 cm long and 7.62 cm apart.

For fly ash separation, the electric field voltage is + or −25,000 V. The positively charged unburned carbon particles are attracted to the negative electrode and the negatively charged mineral particles are attracted to the positive electrode. A splitter is placed 15.24 cm downstream from the nozzle to separate the carbon rich and ash rich fractions and direct them to two collection cyclones. The entire separator is swept with laboratory air by applying vacuum to the outlets of the collection cyclones. Sweep flow enters the separator through flow straighteners around the nozzle to control the flow in the separator section. This separator has a capacity of about 8 kg/h in continuous operation and can be used in the batch mode using as little as 100 g fly ash feed. The recovery efficiency of the cyclones is typically greater than 95%.

In this work, we used this parallel plate separator to evaluate a variety of feed fly ash so that their performance curves could be compared. In this application separations are done with the injector in five positions with respect to the splitter-centered on the splitter, displaced 0.635 or 1.27 cm toward the positive plate (left position) and displaced 0.635 or 1.27 cm toward the negative plate (right position). The unburned carbon (attracted to the negative electrode), together with the feed, are then analyzed for carbon and ash content to yield a performance curve. These curves can be used to evaluate the potential of fly ash for separation and to compare the responses of fly ash from different sources.

The louvered plate separator is similar in construction to that of parallel plate. In the separation zone, it has louvered plates versus that of large plane plates in the parallel separator (Fig. 3). The particles charging characteristic are dependent on the type of material used for construction of the tribocharger (copper and Teflon). These charged particles then are directed between two louvered charged plates 45.72 cm long and 7.62 cm apart. For fly ash separations this unit is operated + or −25,000 V on the separator plates. This separator has a capacity of about 3 kg/h in continuous operation and can be used in the batch mode using as little as 50 g of fly ash feed. The recovery efficiency of this separator is typically greater than 95%. The collected products from different sections of louvered plate, from the center, together with the feed, are then analyzed for carbon, ash, and moisture content.

These experimental configurations were used to measure the dependence of the separation on two types of fly ashes. One is derived from the combustion of a Black Creek Pittsburgh seam coal (the fixed carbon content of 7.74 wt%). The other is obtained from the combustion of coal mixed with 10 wt% switch grass — biomass fly ash (the fixed carbon content of 4.84 wt%). The details of size and fixed carbon distribution of the feed ashes are presented in Table 1. The size distribution was determined by a Gilson Wet-Vac sieve shaker. All samples were low

Table 1
Characterization of feed fly ashes

	Ash (%)	Fixed carbon (%)	Cumulative%
Coal fly ash as received	92.2	7.7	100
100 mesh	73	26.2	6.7
200 mesh	63.8	35.4	10.1
325 mesh	75.6	23.6	13.6
500 mesh	89.4	9.8	22.5
−500 mesh	97.1	2.1	100
Biomass fly ash as received	95	4.8	100
100 mesh	71.5	27.7	4.7
200 mesh	80.1	19.1	8
325 mesh	85.6	13.6	12.2
500 mesh	92.1	7.1	20.9
−500 mesh	97.3	1.9	100

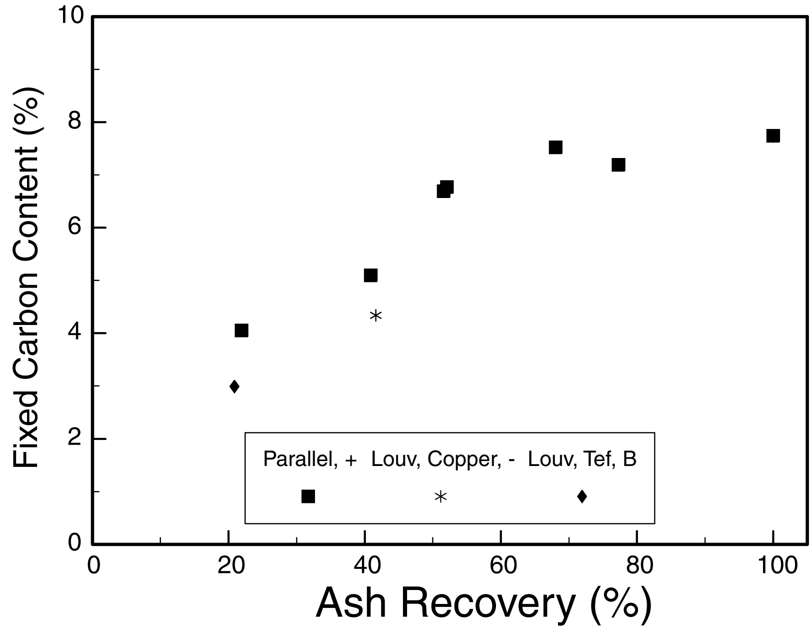

Fig. 4. Ash recovery versus fixed carbon content from different separators (■, product collected from + plate on parallel plate separator; ★, product collected from − plate of the louvered plate separator with a copper tribo charger; ◆, product collected from the bottom of the louvered plate separator with a Teflon tribo charger).

moisture powders which fed easily to the separator and all were separated as received. Using both configurations, two ashes were fed to the separator at feed rates varying from less than 454 g per hour to more than 4,540 g per hour. These feed rates correspond to particle-to-gas mass ratios of 0.1 to 1 g fly ash/g gas. The carbon and mineral concentrate fractions were collected on the negative and positive plates, respectively. After collection and homogenization, the fractions were analyzed for carbon and ash content. A thermogravimetric analyzer TGA-601 manufactured by LECO Corp. was utilized to determine the fixed carbon and ash contents.

3. Results and discussion

The quality of this triboelectrostatic separation can be determined by measuring the cumulative recovery of combustible matter and ash as a function of the position of the splitter in the parallel separator. In this application, separation is done with the injector in five positions with respect to the splitter: centered on the splitter, displaced 0.635 or 1.27 cm toward the positive plate (left position), and displaced 0.635 or 1.27 cm toward the negative plate (right position). The yield of ash rich matter and fixed carbon content on the mineral rich side is presented as a percentage of the total amount of each component in the feed. Typical performance curves for coal combustion fly ash versus different types of separators are shown in Fig. 4. The recovery of mineral rich matter in the feed on the positively charged side is nearly 77% for coal fly ash with the splitter located 1.27 cm to the right position. This product, containing 77% of the mineral matter, contains 7.19% of the fixed carbon compared to 7.74% in the feed which indicates the selectivity of this process. A slight increase in the fixed carbon content to 7.52% is observed as the splitter is moved 0.635 cm to the right position; however, the ash recovery drops to around 68%. Further

Table 2
Triboelectrostatic separation of the coal fly ash as received via a louvered plate separator

Sample	Ash recovery (%)	Moisture (%)	Ash (%)	Fixed carbon (%)
Coal fly ash as received, utilized copper tribo charger	100	0.9	91.3	7.7
Product collected in (+) plate	41.6	0.6	95.1	4.3
Product collected in (−) plate	17.8	1.2	90.3	8.5
Product collected in the bottom	40.6	1.2	88.2	10.6
Coal fly ash as received, utilized Teflon tribo charger	100	0.9	91.3	7.7
Product collected in (+) plate	20.2	0.8	92.2	6.9
Product collected in (−) plate	58.9	0.7	89.7	9.6
Product collected in the bottom	20.8	1.7	95.2	2.9

Table 3
Triboelectrostatic separation of coal and biomass (coal + 10 wt% switch grass) fly ash as received via a parallel plate separator

Parallel plate separator, splitter position, center	Ash recovery (%)	Moisture (%)	Ash (%)	Fixed carbon (%)
Coal fly ash as received	100	0.7	91.7	7.7
Product collected in the (+) electrode	50.9	0.8	92.8	6.3
Product collected in the (−) electrode	43.8	1.3	87.2	11.5
Biomass fly ash as received	100	1.0	94.1	4.8
Product collected in the (+) electrode	48.6	1.0	94.1	4.8
Product collected in the (−) electrode	42.0	1.2	93.3	5.5

reducing the fixed carbon content to 6.7% could be achieved by adjusting the splitter to the center position in the separation chamber. The ash recovery for this collected product is around 52%. The mineral rich product which contains 5.1% of fixed carbon along with an ash recovery of 41% could be achieved by adjusting the position of the splitter 0.635 cm to the left position. Further decreasing the fixed carbon content to 4% with an ash recovery of 22% could be obtained by repositioning the splitter 1.27 cm to the left position. This significant reduction of the fixed carbon content from 7.74% in the feed to 4% in the ash rich product is at the expense of the recovery of the mineral matter. Fig. 4 also illustrates the results obtained from the louvered plate separator with different types of construction materials for the tribocharger. A product with a fixed carbon content of 4.3% and 42% of ash recovery could be collected from the negative side of a louvered plate separator with a copper tribocharger. Furthermore, a product with less than 3 wt% of fixed carbon at 21% recovery was achieved by collecting the products passing between both louvered plates via a Teflon tribocharger.

The louvered plate separator with the capability for multiple separated outputs was utilized to collect the possible fractionated ash components. Visual observation on the separated products (Table 2) indicated that there are three distinguishable portions on the louvered plate. This suggests that fractionation affects the separated products. The different materials have different work functions and will take on different charges when in contact with the tribocharger. Therefore, the combination of external electric force, electron charge to mass ratio, and particle initial velocity will result in different trajectories for different particles. The lighter particles will be deposited on the upper portion of the louvered plate. The heavier particles will be collected on the lower portion of the louvered plate. Those particles that did not charge and/or lost their charges prior to entering the separation zone will pass through the center.

The effects of different tribocharger material of construction (copper versus Teflon) on the separations were analyzed. The charging phenomena may vary as the construction material of the tribocharger changes. The results shown in Table 2 indicate that the tribocharger material of construction affects the separation. With the copper tribocharger, 59% of the feed was charged and collected on the plates. In the case of Teflon tribocharger, the recovery increased to 79% of the feed. These results suggest that Teflon may be a more efficient charger than copper for fly ash separation. The deposition pattern of the collected material is also different for the two tribochargers studied. In the copper tribocharger case, the majority of the products are collected on the positive plate. However, in the case of the Teflon tribocharger, most of the products are deposited on the negative plate. Therefore, the deposit patterns and quantity of the collected products could be adjusted by utilizing different material of construction for the tribochargers. A product with less than 3 wt% fixed carbon contents was generated by utilizing the Teflon charger. This product can be used for cement application without further purification.

The dry triboelectrostatic separations of fly ash derived from both coal combustion and the combustion of coal mixed with 10 wt% switch grass (biomass) were also performed in the parallel plate separator with the splitter position in the center. The results of this study are tabulated in Table 3.

The results in Table 3 indicate that the simple parallel plate separator is able to provide some separation on coal combustion fly ash. However, in the case of fly ash derived from combustion of coal mixed with 10 wt% switch grass, the parallel plate separator provided a poor quality separation. It is speculated that the poor separations are related to the physical and/or chemical nature of the coal and biomass fly ashes. Microscopic image analysis of the separated products and the parent ashes were conducted. These images indicated that there are more carbon particles trapped within and attached to larger ash particles in the case of biomass fly ash than that of coal combustion fly ash. In addition, the biomass-derived fly ash contained a

Table 4
Samples analyses of switch grass, coal fly ash and biomass fly ash

	Coal ash	Switch grass feed	Biomass ash
Ash	90.6	3.5	94.1
Al_2O_3	21.1	0.8	19.1
CaO	5.8	15.4	5.8
Fe_2O_3	13.1	0.6	10.8
K_2O	1.4	6.0	3.3
MgO	1.0	3.8	1.6
NaO	1.0	1.1	0.9
SiO_2	54.9	38.3	55.8
TiO_2	1.1	0.1	0.9
P_2O_5	0.3	3.5	1.3

Table 5
Surface analyses (XPS) of feed ashes

	Coal ash	Biomass ash
C	27.0	24.0
O	48.8	50.3
F	0.3	0.4
Na	0.3	0.5
Mg	0.7	1.2
P	0.2	0.6
S	3.6	4.7
K	0	0.5
Ca	3.1	3.8
Fe	1.1	1.5

significant amount of unburned grass. The unburned grass accounted for approximately more than 20% of the total fixed carbon. It is possible that the unburned grass might affect the flow patterns in the charging zone and discharge other charged particles together with the ash-encapsulated carbon, thus contributing to the poor quality separation. The other possible factor is the chemical nature of the biomass fly ash. Table 4 illustrates the detailed analyses of the fly ash samples. With the 10 wt% mix of the switch grass, the final biomass fly ash showed some distinguishable differences compared with coal ash only. For example, the K_2O increased from 1.4% in coal ash to 3.37% in biomass ash. MgO also shows significant increase from 1.06% in coal ash to 1.67% in biomass ash. Furthermore, the surface analyses (XPS) of the feed ashes were conducted and are illustrated in Table 5. The surface concentration of Na, Mg, K, Ca, Fe in the biomass fly ash were higher than that of coal combustion fly ash. It is speculated that the additional Na, Mg, K, Ca, and Fe found in the biomass ash may change the concentration of electron vacancies on the fly ash surface [14]. As a result of this, the electric behavior varies, thus affecting the separation.

4. Conclusions

Preliminary data on coal combustion fly ash separation indicate that the material of construction for the tribocharger in the louvered plate separator affects both the deposition pattern and the quantity of recovery of the separated products. The separators utilized in this study cannot qualitatively provide a separation for biomass fly ash. It is probably due to the physical/chemical nature of the biomass fly ash which is significantly different from that of coal fly ash.

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